PATENT SPECIFICATION

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(54) SEMICONDUCTOR ACTUATED SWITCHING DEVICES

(71) We, STANDARD TELEPHONES AND CABLES LIMITED, a British Company of 190 Strand, London W.C.2, England, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to semiconductor switching devices, and especially to such devices in which the movable element is a flexible member of a semiconductor material.

Our Patent Specification No. 1,211,499 describes the manufacture of semiconductor devices such as diodes and strain gauges in which the semiconductor material used is silicon. The devices described therein include strain gauges using strip-like members which when subjected to strain change the electrical resistance thereof. With such a strain gauge metallic contacts are attached to a silicon strip-like member and the strain to which such a member is subjected generates a changed electrical resistance which can be sensed by a suitable measuring instrument.

An object of the present invention is to provide a low power switching device in which flexible members of semiconductor material provide the moving and contact operating elements.

According to the present invention there is provided a switching device in which the switching action of the device is produced by movement of one or more thin flexible strip-like members of silicon, which movement causes the operation of electrical contacts, in which the or each said strip-like member of silicon is secured at least at one of its ends, and in which the action of a non-mechanical controlling influence on the strip-like member or members of silicon produces mechanical movement thereof to cause the said contact operation.

Thus it will be seen that this invention arises from the appreciation that switching relay devices can be developed for low power applications which are in effect the inverse of the strain gauge arrangements referred to above.

At this point it is worth mentioning the methods used to make the devices. In our above-mentioned Patent Specification, we have described a method of manufacturing a semiconductive device, including the steps of providing a silicon substrate having a p–n junction therein, masking the surface of the n-type layer to expose that area or those areas thereof to be etched, and etching the exposed area or areas with an etch solution of a diamine, water and either catechol or catechol derivatives which form a complex with silicon, which solution is selective such that it does not act upon the p-type layer, the maximum depth of the etched areas being limited by the p–n junction.

It was previously thought that the selective nature of the etching process was due to electro-chemical effects at the p–n junction, however further work indicates that the inhibiting effect which produces the selectivity is due in the main to the concentration of a particular dopant in the silicon exceeding a minimal level. Thus for example the presence of a boron dopant at a concentration of at least 4×10^{19} atoms per cc. causes etching to be inhibited.

The devices to be described in the present specification may be made using processes extant in the semiconductor industry, i.e. masking and etching processes (including etching processes such as that of the above-mentioned Patent Specification), together with various deposition processes.

Embodiments of the invention will now be described with reference to the accompanying drawings, in which

Figs. 1 and 2 are somewhat simplified representations of switching devices in which the controlling influence is heat.

Figs. 3a and 3b indicate schematically the operating principles of a device in which the controlling influence is electrostatic.

Fig. 4 is a perspective view of one form which the electrostatically operated device can take.

Such devices need to be driven, and there are various ways to do this by the exercise of a

controlling influence on the movable element, or on one or more movable elements where a device has more than one such element. These ways include the use of thermal expansion. This can be done in a manner analogous to that of a thermostat, i.e. by providing the flexible member with a layer of a material of a different coefficient of expansion, so that local heat tends to curl the member, or by local heating to give a local expansion.

Another way is the use of electrostatic forces, in which a thin member of silicon is parallel to a counter-electrode, and a suitable electrical potential is applied between them.

In the arrangement shown in Fig. 1 there is an armature 1 whose legs are each coupled by a thin strip 2, 3 to a fixed part 4. This structure is formed as an integral structure from silicon using manufacturing processes of the type referred to above.

The armature 1 and the support 4 have the same thickness as the slice or sheet of silicon from which the structure is made, while the flexible strips 2 and 3 are defined by a boron diffusion which is unattacked by an ethylene diamine-catechol-water etch. By suitable choice of the points of attachments of the strips to the armature and the support we obtain a bistable structure. The strips 2 and 3 are in a state of tension due to the shrinkage of the lattice constant produced by the use of a boron dopant.

The contacts to be controlled by the device include metallic strips such as 5 deposited on the armature, each of which is movable with the armature between a position in which it closes a pair of stationary contacts (not shown) and a position in which it does not close those contacts. The dashed line 6 is indicative of the location of the stationary contacts with which the strip 5 co-operates. It will be appreciated that the armature shown can control two or more contact sets of the same general type.

The operation of the device is effected by differential heating of the two flexible strips 2, 3, which causes the armature to switch in a bistable manner between two different positions. One such position is as shown, while the other has the right-hand end low and the left-hand end high.

Although Fig. 1 has been described for a bistable device it will be appreciated that monostable or astable devices can be made using the same general principles.

An extension of the principles of Fig. 1 will be seen in Fig. 2 where we have four strips 10, 11, 12, 13 connecting the armature limbs to the fixed part. With this use of strips on both sides of the armature, reducing the tension in one of them, e.g. by thermal expansion, causes a torque which turns the structure from its one to its other state. Thus the armature "flips" when the tension in strips 11 and 12 is reduced as compared with that in the strips 10 and 13 until the anti-clockwise torque due to strips 11 and 12 is less than the clockwise torque due to the strips 10 and 13. In this arrangement, as in that of Fig. 1, the fixed contacts with which contacts carried by the armature co-operate limits the amount by which the armature can rotate.

The condition of such a thermal latching device can be detected from the resistance of a driving element, due to the piezo-resistive effect.

In the electrostatically-operated versions of the switching device, the armature, see Fig. 3a, consists of a tongue of thin silicon with an intrinsic curl, which can flatten against a fixed electrode. Thus it is possible to move a contact carried by the tongue a sensible distance, but it may not be possible in this way to obtain adequate contact pressure. To do this, see Fig. 3b, a capacitor is formed at 14 between an area of the armature and the fixed electrode which is sufficient to generate the required contact pressure. In this case operation is effected by charging the capacitor.

Fig. 4 shows one realisation of a two-pole normally-operated device using the electrostatic principle. The middle wide strip 15 is the driving electrode while the two narrow outer strips 16 and 17 are metallised to carry the current to be switched. Each of them co-operates with one or more fixed contacts such as 18.

The strip 15 co-operates with a flat metallic electrode 19 to provide a capacitor. For this purpose the strip 15 is also metallised, and energising the capacitor thus formed causes the electrode structure to move to its closed condition. On discharge of the capacitor the springyness of the electrode structure returns it to its rest position.

The ridges 20 and 21, at the ends of the electrodes structure are of glass, preferably one of the glasses sold under the Registered Trade Mark PYREX.

It will be appreciated that a single silicon chip can have one or more devices of this tyre bonded to a flat substrate with the fixed electrodes and contacts photo-etched on to it. This is so done that none of the bonding material flows under the flexing parts. Local heating needed for this is effected by passing a current through a specially-designed part of the structure so as to reflow a suitable solder.

Silicon is used mainly because it can be readily batch fabricated with high precison, and its strain characteristics can be controlled without excessive difficulty.

The contacts used in devices such as described above can be so designed that multiple contact is made using thin silicon fingers. This is analogous to the split contact ends used with electro-magnetic relays.

WHAT WE CLAIM IS:—

1. A switching device in which the switch-

ing action of the device is produced by movement of one or more thin flexible strip-like members of silicon, which movement causes the operation of electrical contacts, in which the or each said strip-like member of silicon is secured at least at one of its ends, and in which the action of a non-mechanical controlling influence on the strip-like member or members of silicon produces mechanical movement thereof to cause the said contact operation.

2. A device as claimed in claim 1, and in which the controlling influence for the device is heat the action of which on the or each said strip-like member of silicon causes the said movement of the or each strip-like member.

3. A device as claimed in claim 2, which includes an armature having two parallel limbs interconnected by a third limb, and a fixed portion to which each of said parallel limbs is coupled by a said strip-like member of silicon, in which the armature, the fixed portion and the strip-like members are an integral structure of silicon, and in which the heat which forms the device's controlling influence acts differently on the silicon strip-like members to move the armature between two different positions to effect said contact operation.

4. A device as claimed in claim 3, and in which the two parallel limbs of the armature are each coupled to the fixed portion by two parallel said strip-like members of silicon.

5. A device as claimed in claim 3 or 4, and in which at least one of the limbs of the armature carries a metal strip which in one position of the armature completes an electrical circuit between two stationary contacts.

6. A device as claimed in claim 1, and in which the mechanical movement of the strip-like member or members of silicon caused by the controlling influence is effected by an attractive force generated capacitively, so that the controlling influence is by its nature electrostatic.

7. A device as claimed in claim 6, and in which there is a single said strip-like member of silicon, which member is a relatively wide silicon strip which co-operates capacitively with a fixed metallised area, and in which the silicon strip is coupled to one or more contact carrying members.

8. A device as claimed in claim 6 or 7, and in which the strip-like member of silicon, or at least one said strip-like member of silicon carries one or more metal strips on its surface, the or each said metallic strip co-operating with a pair of stationary contacts in at least one of the positions of the said strip-like member of silicon.

9. A switching device, substantially as described with reference to Fig. 1, Fig. 2, Fig. 3*b* or Fig. 4 of the accompanying drawings.

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1584914 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*

Fig. 1.

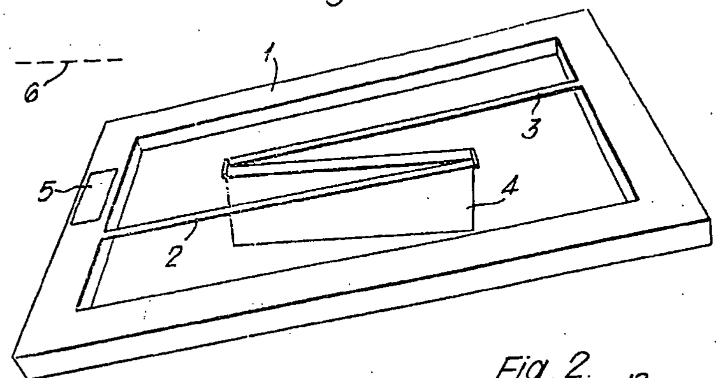

Fig. 2.

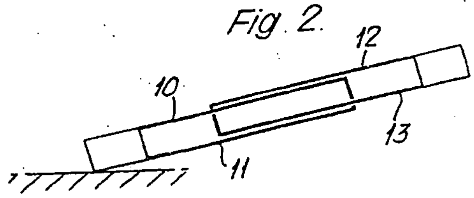

Fig. 3a.

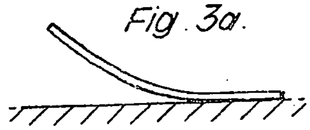

Fig. 3b.

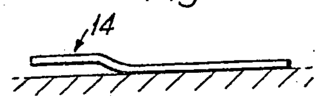

Fig. 4.